6. Land Use Issues

Overview

Land use change and forestry issues are important to national and global inventories of greenhouse gases in two ways:

- Vegetation can "sequester" or remove carbon dioxide from the atmosphere and store it for potentially long periods in above- and below-ground biomass, as well as in soils. Soils, trees, crops, and other plants may make significant contributions to reducing net greenhouse gas emissions by serving as carbon "sinks."
- Humans can alter the biosphere through changes in land use and forest management practices and, in effect, alter the quantities of atmospheric and terrestrial carbon stocks, as well as the natural carbon flux among biomass, soils, and the atmosphere.

Land use issues are of particular interest to the United States because U.S. forests and soils annually sequester large amounts of carbon dioxide. Much of the forest land in the United States was originally cleared for agriculture, lumber, or fuel in the hundred years prior to 1920. Since then, however, much of the agricultural and pasture land has reverted to forest land, increasing its ability to sequester atmospheric carbon dioxide.

The amount of carbon being sequestered annually is uncertain, in part because of an absence of data and difficulties in measuring sequestration. Moreover, in addition to technical uncertainties, there are also policy and accounting questions about the aspects of the biological carbon cycle that would be included in national inventories as anthropogenic emissions and removals.

The revised guidelines for national emissions inventories published in 1997 by the Intergovernmental Panel on Climate Change (IPCC) stipulate the inclusion of carbon sequestration through land use and forestry in national greenhouse gas inventories as an offset to gross greenhouse gas emissions from other sources.[133] The U.S. Environmental Protection Agency (EPA) estimates annual U.S. carbon sequestration for the year 2000 at 246 million metric tons carbon equivalent, a decline of approximately 17.7 percent from the 299 million metric tons carbon equivalent sequestered in 1990 (Table 31). Between 1990 and 2000, land use change and forestry practices represented an offset of approximately 15.4 percent of total U.S. anthropogenic carbon dioxide emissions.

Land Use Change and Forestry Carbon Sequestration

The EPA's estimates for carbon sequestration from land use change and forestry in 2000 include four main components: (1) changes in forest carbon stocks (210 million metric tons carbon equivalent or 85.4 percent of the total), (2) changes in agricultural soil carbon stocks (18 million metric tons carbon equivalent or 7.3 percent of the total), (3) changes in carbon stocks in urban trees (16 million metric tons carbon equivalent or 6.5 percent of

Table 31. Net Carbon Dioxide Sequestration from U.S. Land Use Change and Forestry, 1990 and 1995-2000
(Million Metric Tons Carbon Equivalent)

Component	1990	1995	1996	1997	1998	1999	2000
Forests	268[a]	267[a]	267[b]	207[b]	205[b]	208[b]	210[b]
Urban Trees	16[a]	16[a]	16[a]	16[a]	16[a]	16[a]	16[a]
Agricultural Soils	10[a]	16[a]	16[a]	17[b]	18[b]	19[b]	18[b]
Landfilled Yard Trimmings	5[a]	3[a]	3[a]	3[b]	2[b]	2[b]	2[b]
Total	**299[a]**	**303[a]**	**302[b]**	**242[b]**	**242[b]**	**245[b]**	**246[b]**

[a]Estimate based on historical data.
[b]Estimate based on a combination of historical data and projections.
Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

[133]Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), web site www.ipcc.ch/pub/guide.htm.

Global Estimates of Carbon Sequestration Through Land Use and Forestry Activities

Two recent studies have attempted to estimate global levels of carbon sequestration. A 2000 report by the Intergovernmental Panel on Climate Change (IPCC) on land use, land use change and forestry (LULUCF) activities provides a range of values for global carbon sequestration attributable to land use and forestry practices. The IPCC maintains that accounting for the amount of carbon being sequestered annually involves a high degree of uncertainty due to lack of data and to difficulties in measuring sequestration. Further, the report states that there are policy and accounting uncertainties regarding which aspects of the biological carbon cycle should be included in national inventories as anthropogenic emissions and removals. Nevertheless, the IPCC does provide values for carbon sequestration attributable to LULUCF activities.[a]

The report provides estimates for carbon stock changes resulting from LULUCF activities under IPCC guidelines and, alternatively, under three United Nations Food and Agriculture Organization (FAO) "definitional scenarios." The FAO definitional scenarios are based on different accounting methods, which assume that area conversion rates remain constant and exclude carbon in soils and wood products. All the accounting scenarios provide estimates for sequestration within UNFCCC Annex I countries[b] during the first commitment period (2008-2012) of the Kyoto Protocol. The FAO scenarios include the harvest / regeneration cycle, because regeneration is defined as reforestation. Three FAO accounting approaches are distinguished:

- In the FAO *Land-Based I Accounting Scenario*, the stock change over the full commitment period is measured, including stock losses during harvest, as well as delayed emissions from dead organic matter for reforestation. This approach results in estimated Annex I emissions of 333 to 849 million metric tons carbon equivalent per year from land use and forestry activities.
- In the FAO *Land-Based II Accounting Scenario*, the carbon stock change between the beginning of the activity and the end of the commitment period is measured, including decay from harvest. This approach results in estimates for the Annex I countries that range from net sequestration of 205 million metric tons carbon equivalent per year to net emissions of 280 million metric tons carbon equivalent per year from land use and forestry activities.
- In the FAO *Activity-Based Accounting Scenario*, only the accumulation of carbon in new forest stands and new dead organic matter is counted under reforestation. This approach results in estimates for the Annex I countries that range from net sequestration of 483 million metric tons carbon equivalent per year to net emissions of 3 million metric tons carbon equivalent per year from land use and forestry activities.

Other global studies also provide a wide range of estimates of carbon sequestration. A working paper developed by the CICERO Center for International Climate and Environmental Research indicates that, globally, the area available for forest plantations could range from 345 million to 510 million hectares, and that an estimated 2.9 billion metric tons of carbon per year can be removed from the atmosphere in forest plantations.[c] In contrast, a 1991 study by Nordhaus[d] suggests that approximately 0.3 billion metric tons of carbon could be captured annually over a period of 75 years. The fact that the estimates from the two studies differ by a full order of magnitude illustrates the difficulties and uncertainties involved in estimating carbon sequestration.

The table on the opposite page shows estimates of annual carbon sequestration totals for Annex I and non-Annex I countries that could result from LULUCF activities under the Kyoto Protocol. According to those estimates, more than 300 million metric tons of carbon sequestration "credits" could be made available annually through LULUCF activities in the Annex I countries, and the potential for sequestration is much greater in the non-Annex I countries. The greatest potential for carbon sequestration is in forestry-related activities.[e]

(continued on page 75)

[a]Intergovernmental Panel on Climate Change, *Summary for Policymakers: Land Use, Land-Use Change, and Forestry* (Cambridge, UK: Cambridge University Press, May 2000), p. 4, web site www.ipcc.ch / pub / srlulucf-e.pdf.

[b]As designated in the United Nations Framework Convention on Climate Change (UNFCCC).

[c]H. Kolshus, *Carbon Sequestration in Sinks: An Overview of Potential and Costs*, CICERO Working Paper 2001: 11 (Oslo, Norway: CICERO Center for International Climate and Environmental Research, November 2001), web site www.cicero.uio.no / media / 1616.pdf.

[d]W.D. Nordhaus, "The Cost of Slowing Climate Change: A Survey," *The Energy Journal*, Vol. 12, No. 1 (1991), pp. 37-65.

[e]H. Kolshus, *Carbon Sequestration in Sinks: An Overview of Potential and Costs*, CICERO Working Paper 2001: 11 (Oslo, Norway: CICERO Center for International Climate and Environmental Research, November 2001), web site www.cicero.uio.no / media / 1616.pdf.

Global Estimates of Carbon Sequestration Through Land Use and Forestry Activities (Continued)

Estimates of Annual Carbon Sequestration Through LULUCF Activities by 2010 Under Provisions of the Kyoto Protocol
(Million Metric Tons Carbon per Year)

Activities	Annex I Countries	Non-Annex I Countries
Article 3.3		
Reduced Deforestation	60 (0-90)	1,698
Afforestation and Reforestation	26 (7-46)	373 (190-538)
Article 3.4		
Croplands (e.g., reduced tillage, erosion control)	75	50
Forests (e.g., enhanced regeneration, fertilization)	101	69
Grazing Lands (e.g., herd, fire, and wood management)	69	168
Agroforests (e.g., management of trees in agriculture)	12	14
Urban land (e.g., tree, waste and wood product management)	1	1
Deforested Land to Agroforest Instead of Pasture/Crop	0	391
Severely Degraded Land to Crop, Grass, or Forest land	1	3
Cropland to Grassland	24	14
Total for Article 3.4	**300**	**710**

Notes: Numbers in parentheses represent a range of estimates. Quantities for Articles 3.3 and 3.4 cannot be summed, because they may apply for the same area. Totals may not equal sum of components due to independent rounding.

Sources: H. Kolshus, *Carbon Sequestration in Sinks: An Overview of Potential and Costs*, CICERO Working Paper 2001: 11 (Oslo, Norway: CICERO Center for International Climate and Environmental Research, November 2001), p. 6, web site www.cicero.uio.no/media/1616.pdf; I. Noble and R.J. Scholes, "Sinks and the Kyoto Protocol," *Climate Policy*, Vol. 1 (2001), pp. 5-25; and F. Missfeldt and E. Haites, "The Potential Contribution of Sinks to Meeting Kyoto Protocol Commitments," *Environmental Science and Policy*, Vol. 4, No. 6 (2001), pp. 269-292.

the total), and (4) changes in carbon stocks in landfilled yard trimmings (2 million metric tons carbon equivalent or 0.8 percent of the total).[134]

The EPA's estimates for carbon sequestration in forests are based on carbon stock estimates developed by the U.S. Forest Service, U.S. Department of Agriculture (USDA), employing methodologies that are consistent with the 1996 IPCC guidelines. The USDA estimates of carbon stocks in urban trees were based on field measurements in ten U.S. cities and data on national urban tree cover, again employing a methodology consistent with the 1996 IPCC guidelines. Estimates for sequestration in agricultural soils were based on changes in carbon stocks in mineral and organic soils resulting from agricultural land use and land management, as well as emissions of carbon dioxide resulting from the use of crushed limestone and dolomite on soils. Methodologies drawn from the IPCC guidelines were used to derive all components of changes in agricultural soil carbon stocks. The EPA estimates for carbon stocks in landfilled yard trimmings are based on the EPA's own method of examining life-cycle greenhouse gas emissions and sinks associated with solid waste management.[135]

The EPA's carbon flux estimates, with the exception of those from wood products, urban trees, and liming, are based on surveys of U.S. forest lands and soils carried out at 5- or 10-year intervals by the U.S. Forest Service. The resulting annual averages are applied to years between surveys. Annual estimates of carbon fluxes between survey years are interpolated and, therefore, change little from year to year, except when a new assessment is made. For landfilled yard trimmings, periodic solid waste survey data are interpolated to derive annual storage estimates. The most current national forest and soil surveys were completed for the year 1997; thus, carbon flux estimates from forests are derived in part from modeled projections for future years. Data on carbon fluxes from urban trees, collected over the decade 1990-2000, were applied to the entire time series.[136]

[134] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.
[135] U.S. Environmental Protection Agency, *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 2nd Edition, EPA-530-R-02-006 (Washington, DC, May 2002), web site www.epa.gov.
[136] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

Satellite Data Indicate That Forests Store 700 Million Metric Tons of Carbon Annually

In a recent study, investigators have used satellite data from the National Aeronautics and Space Administration (NASA) to construct detailed maps of forest carbon pools, sources, and sinks in North America, Europe, and Russia. Their findings indicate that approximately 700 million metric tons of carbon is stored in those forests annually—equivalent to approximately 11.5 percent of global energy-related carbon dioxide emissions in 1999. The data indicate that, with the exception of Canada's boreal forests, which were found to be losing carbon, most northern forests are actively storing carbon. Russia, which contains the most forest land, accounted for approximately 40 percent of the biomass carbon sink. The researchers reported that about 61 billion tons of carbon is contained in the wood components of these northern forests, with American and European forests containing more carbon per unit of area than either Canadian or Russian forests (56 versus 41 tons of carbon per hectare).[a]

[a]R. Myneni et. al, "Forests Storing 700 Million Tons of Carbon Per Year," *UniSci Daily University Science News* (December 12, 2001), web site http://unisci.com/stories/20014/1212012.htm.

Changes in Forest Carbon Stocks

Worldwide, the most significant anthropogenic activity that affects forest carbon sequestration is deforestation, particularly that of tropical forests. During the 1980s, tropical deforestation is projected to have resulted in approximately 6 billion metric tons of carbon dioxide emissions to the atmosphere annually. This value represents approximately 23 percent of global carbon dioxide emissions resulting from anthropogenic activities during the 1980s. Approximately 7 percent of global carbon dioxide emissions were compensated for by carbon sequestration as a result of forest re-growth in the Northern Hemisphere.[137] In the United States, the most significant pressures on the amount of carbon sequestered through forest lands are land management activities and the continuing effects of past changes in land use. These activities directly affect carbon flux by shifting the amount of carbon accumulated in forest ecosystems.[138] Land management activities affect both the stocks of carbon that can be stored in land-based carbon sinks, such as forests and soils, and the flows, or fluxes, of carbon between land-based sinks and the atmosphere.

Forests are multifaceted ecosystems with numerous interrelated components, each of which stores carbon. These components include:

- Trees (living trees, standing dead trees, roots, stems, branches, and foliage)
- Understory vegetation (shrubs and bushes, roots, stems, branches, and foliage)
- Forest floor (fine woody debris, tree litter, and humus)
- Down dead wood (logging residue and other dead wood on the ground, stumps, and roots of stumps)
- Organic material in soil.

As a result of natural biological processes occurring within forests, as well as anthropogenic activities, carbon is constantly cycling through these components and between the forest and the atmosphere. The net change in overall forest carbon may not always be equal to the net flux between forests and the atmosphere, because timber harvests may not necessarily result in an instant return of carbon to the atmosphere. Timber harvesting transfers carbon from one of the seven forest components or "forest pools" to a "product pool." Once carbon is transferred to a product pool, it is emitted over time as carbon dioxide as the product combusts or decays. Emission rates vary significantly, depending on the type of product pool that houses the carbon.[139]

In the United States, enhanced forest management, regeneration of formerly cleared forest areas, and timber harvesting have resulted in the annual sequestration of carbon throughout the past decade. Since the 1920s, deforestation for agricultural purposes has become a practically nonexistent practice. More recently, managed growth practices have become common in eastern forests, greatly increasing their biomass density over the past 50 years. In the 1970s and 1980s, federally sponsored tree planting and soil conservation programs were embraced. These programs resulted in the reforestation of formerly harvested lands, improvement in timber management activities, soil erosion abatement, and the

[137]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.
[138]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.
[139]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

conversion of cropland to forests. Forest harvests have also affected carbon sequestration. The majority of harvested timber in the United States is used in wood products. The bulk of the discarded wood products are landfilled; thus, large quantities of the harvested carbon are relocated to long-term storage pools rather than to the atmosphere. The size of wood product landfills has increased over the past century.[140]

According to the EPA (Table 32), between 1990 and 2000, U.S. forest and harvested wood components accounted for an average annual net sequestration of 210 million metric tons carbon equivalent, resulting from domestic forest growth and increases in forested land area. Over the same period, however, increasing harvests and land-use changes have resulted in a decrease of approximately 22 percent in the overall rate of annual sequestration.

Changes in Urban Tree Carbon Stocks

Urban forests make up a considerable portion of the total tree canopy cover in the United States. Urban areas, which cover 3.5 percent of the continental United States, are estimated to contain about 3.8 billion trees, accounting for approximately 2.8 percent of total tree cover. The EPA's carbon sequestration estimates for urban trees are derived from estimates by Nowak and Crane,[141] based on data collected from 1990 through 2000. Net carbon dioxide flux from urban trees is estimated at 16 million metric tons carbon equivalent annually from 1990 through 2000 (Table 31).[142]

Changes in Agricultural Soil Carbon Stocks

The amount of organic carbon in soils depends on the balance between addition of organic materials and loss of carbon through decomposition. The quantity and quality of organic matter within soils, as well as decomposition rates, are determined by the interaction of climate, soil properties, and land use. Agricultural practices—including clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding—can alter organic matter inputs and decomposition, causing a net flux of carbon to or from soils. The IPCC methodology, which is used by the EPA to estimate the net flux from agricultural soils (Table 33), is divided into three categories of land use and land management activities: (1) agricultural land use and land management activities on mineral soils; (2) agricultural land use and land management activities on organic soils; and (3) liming of soils. Of the three activities, the

Table 32. Net Carbon Dioxide Sequestration in U.S. Forests, 1990 and 1995-2000
(Million Metric Tons Carbon Equivalent)

Description	1990[a]	1995[a]	1996[a]	1997[b]	1998[b]	1999[b]	2000[b]
Forest Carbon Stocks	**211**	**211**	**211**	**149**	**149**	**149**	**149**
Trees	128	128	128	122	122	122	122
Understory	3	3	3	4	4	4	4
Forest Floor	7	7	7	-8	-8	-8	-8
Down Dead Wood	15	15	15	16	16	16	16
Forest Soils	58	58	58	15	15	15	15
Harvested Wood Carbon Stocks	**57**	**56**	**56**	**58**	**56**	**59**	**61**
Wood Products	13	15	15	16	14	17	18
Landfilled Wood	44	41	41	42	42	42	43
Total	**268**	**267**	**267**	**207**	**205**	**208**	**210**

[a]Estimates based on historical data.
[b]Estimates based on a combination of historical data and projections.
Notes: The sums of the annual net stock changes in this table (shown in the "Total" row) represent estimates of the actual net flux between the total forest carbon pool and the atmosphere. Forest values are based on periodic measurements; harvested wood estimates are based on annual surveys. Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

[140]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), p. 129, web site www.epa.gov.
[141]D.J. Nowak and D.E. Crane, "Carbon Storage and Sequestration by Urban Trees in the United States," *Environmental Pollution*, Vol. 116, No. 3 (2001), pp. 381-389.
[142]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

use and management of mineral soils is estimated to be the most significant contributor to total flux from 1990 through 2000.[143]

Changes in Landfilled Yard Trimming Carbon Stocks

Carbon stored in landfilled yard trimmings can remain indefinitely. In the United States, yard trimmings (grass clippings, leaves, and branches) make up a considerable portion of the municipal waste stream, and significant amounts of the yard trimmings collected are discarded in landfills. Both the amount of yard trimmings collected annually and the percentage of trimmings landfilled have declined over the past decade, and net carbon dioxide sequestration in landfilled yard trimmings has declined accordingly (Table 31). The EPA's methodology for estimating carbon storage relies on a life-cycle analysis of greenhouse gas emissions and sinks associated with solid waste management.[144]

Land Use and International Climate Change Negotiations

In past international negotiations on climate change, the United States and many other countries have maintained that the inclusion of LULUCF activities in a binding agreement that limits greenhouse gas emissions is of the utmost importance; however, issues of whether and how terrestrial carbon sequestration could be accepted for meeting various commitments and targets have remained subjects of complex and difficult international negotiations on climate change.

Many of the countries involved in climate change negotiations have agreed that implementation of LULUCF activities under an international climate change agreement may be complicated by a lack of clear definitions for words such as "reforestation" and "forest." Further, implementation may be hindered by the lack of effective accounting rules. According to researchers at the Pew Center on Global Climate Change,[145] implementation of LULUCF provisions in an international climate change agreement raises many issues for such activities and / or projects, such as:

- What is a direct human-induced activity?
- What is a forest and what is reforestation?
- How will uncertainty and verifiability be addressed?
- How will the issues of (non) permanence and leakage be addressed?
- Which activities beyond afforestation, reforestation and deforestation (ARD), if any, should be included, and what accounting rules should apply?
- Which carbon pools and which greenhouse gases should be considered?

Uncertainties related to data issues have also slowed international negotiations on climate change.

The most recent UNFCCC climate negotiations, which took place at the Conference of the Parties (COP) in Bonn, Germany, in July 2001 (COP-6.5) and Marrakech, Morocco, in November 2001 (COP-7) led to an agreement called the Marrakech Accords. LULUCF activities were debated throughout the negotiations, and it is believed that the LULUCF issue was one of the main

Table 33. Net Carbon Dioxide Sequestration in U.S. Agricultural Soils, 1990 and 1995-2000
(Million Metric Tons Carbon Equivalent)

Description	1990	1995	1996	1997	1998	1999	2000
Mineral Soils	18.9[a]	25.1[a]	25.1[a]	25.1[a]	27.2[b]	27.2[b]	27.2[b]
Organic Soils	-6.1[a]	-6.2[a]	-6.2[a]	-6.2[a]	-6.2[b]	-6.2[b]	-6.2[b]
Liming of Soils	-2.6[a]	-2.4[a]	-2.4[a]	-2.4[a]	-2.6[a]	-2.5[a]	-2.6[a]
Total	10.2[a]	16.4[a]	16.4[a]	16.5[a]	18.3[a]	18.5[a]	18.4[a]

[a]Estimates based on historical data.
[b]Estimates based on a combination of historical data and projections.
Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

[143]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.
[144]U.S. Environmental Protection Agency, *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 2nd Edition, EPA-530-R-02-006 (Washington, DC, May 2002), web site www.epa.gov.
[145]G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA; Pew Center on Global Climate Change, June 2000), p. 5, web site www.pewclimate.org / projects / land_use.cfm.

reasons that the negotiations at COP-6 in November 2000 failed. Consensus on including carbon sinks in the Kyoto Protocol was reached only at the very end of the climate change negotiations at COP-7.[146] Should the Kyoto Protocol eventually be ratified, specific implementation rules for LULUCF would have to be developed.

Land Use Data Issues

Uncertainties in the EPA estimates of U.S. carbon sequestration include sampling and measurement errors inherent to forest carbon estimates. The forest surveys engage a statistical sample that represents the expansive variety of growth conditions over large territories. Although more current inventories are conducted annually in each State, much of the existing data may have been collected over more than one year in any given State. Thus, there may be uncertainty about the year associated with the forest survey data. In addition, the existing forest survey data do not include forest stocks in Alaska, Hawaii, and the U.S. territories (although net carbon fluxes from these stocks are anticipated to be insignificant).[147]

Additional uncertainty results from the derivations of carbon sequestration estimates for forest floor, understory vegetation, and soil from models based on forest ecosystem studies. To extrapolate results of these studies to the forested lands in question, an assumption was made that the studies effectively described regional or national averages. This assumption may result in bias from applying data from studies that improperly represent average forest conditions, from modeling errors, and/or from errors in converting estimates from one reporting unit to another.[148]

Aside from the land use data issues and uncertainties discussed above, which are specific to the methodologies used for the EPA estimates, there is concern about larger and more general uncertainty surrounding estimates of terrestrial carbon sequestration. It is anticipated to be difficult, as well as expensive, to determine carbon stock changes over shorter time periods, such as the 5-year periods suggested during international climate change negotiations. This concern is especially problematic if the carbon stocks are large and the stock changes are comparatively small.[149] Several countries involved in the negotiations have maintained that the accounting of terrestrial carbon stock changes over a 5-year commitment period fails to account for the differing dynamics of carbon stocks and fluxes over time.

Accounting for carbon sequestration through land use and forestry practices also raises the issues of "permanence" and "leakage." Carbon sequestration occurring at one time and place presents the issue of whether the carbon will be lost at a later time (permanence) or result in offsetting losses elsewhere (leakage). For example, suppose an international climate change agreement is developed in which changes in carbon stocks within a certain commitment period are used to meet targets. If there is a gap between commitment periods, there will be a possibility for unaccounted losses (or gains) in certain countries. A similar possibility of unaccounted losses will arise if countries in one geographic area receive "credits" for carbon that is sequestered in countries in a different geographic area but subsequent carbon losses remain unaccounted.[150]

Leakage is defined as the unexpected loss of expected carbon sequestration benefits when the displacement of activities or market effects leads to carbon losses elsewhere. For example, avoiding deforestation in one geographic location may accelerate the rate of deforestation in another geographic location. Leakage may also occur through the impact of a large reforestation program on timber prices. Increased availability of timber could result in lower prices, which in turn could cause reduced rates of planting in other locations. Reduced timber prices may also result in the conversion of existing forests for agriculture.[151]

In addition to concerns about uncertainty, permanence, and leakage, a recent scientific study published in the science journal *Nature* has raised questions about carbon sequestration through terrestrial sinks. The authors of the study, Dr. John Lichter and Dr. William Schlesinger, concluded that while forests do sequester carbon dioxide from the air and store it in the soil, the majority of the sequestered carbon is ultimately released back into the

[146]H. Kolshus, *Carbon Sequestration in Sinks: An Overview of Potential and Costs*, CICERO Working Paper 2001: 11 (Oslo, Norway: CICERO Center for International Climate and Environmental Research, November 2001), web site www.cicero.uio.no/media/1616.pdf.

[147]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

[148]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

[149]G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA; Pew Center on Global Climate Change, June 2000), p. 31, web site www.pewclimate.org/projects/land_use.cfm.

[150]G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA; Pew Center on Global Climate Change, June 2000), p. 31, web site www.pewclimate.org/projects/land_use.cfm.

[151]G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA; Pew Center on Global Climate Change, June 2000), p. 32, web site www.pewclimate.org/projects/land_use.cfm.

atmosphere as carbon dioxide when organic soil material decomposes. They maintain that their findings highlight the uncertainty of the role of soils as long-term carbon storage pools and assert that considerable long-term net carbon sequestration in forest soils may be unlikely. Many scientists agree that much work remains to be done on the science surrounding terrestrial carbon sequestration; however, a number of the countries involved in international climate change negotiations assert that the potential for terrestrial carbon sequestration should be embraced, or at the very least, not discounted or overlooked.

In response to the findings presented by Drs. Lichter and Shlesinger, EcoSecurities Ltd., an established environmental finance company that specializes in advising on global warming issues, maintains that their research has been consistently misinterpreted. The company believes that the study's conclusions are inappropriate for two reasons. First, it was never the carbon fertilization effect alone that climate change policymakers considered to be the greenhouse gas mitigation value of forests. Second, because more than 20 percent of all anthropogenic greenhouse gas emissions come from forest conversion and degradation, the avoidance of deforestation should also be viewed as a prime emission reduction measure.[152]

Thus, while there are methods available for estimating the amount of carbon sequestered through U.S. forests and soils, many uncertainties remain in the accounting methodology and overall conceptual feasibility of carbon sequestration both nationally and globally. For this reason, caution should be employed when accounting for and accepting as fact the amount of carbon sequestered through land use and forestry practices, or when making decisions about the amount of sequestered carbon to be treated as an offset to national carbon dioxide emissions.

[152]EcoSecurities Ltd. "'Sinks' and Climate Change. Comment on Recent Reporting on Last Week's *Nature* Journal," Press Release (June 2001), web site www.ecosecurities.com/200about_us/223press_releases/223press_release_sinks_climate.html.